# El Faro Post Cruise Data Processing

A Report Prepared by

The Woods Hole Oceanographic Institution

For

The National Transportation Safety Board

1 September 2016

## Introduction

In April of 2016, on behalf of the National Transportation Safety Board (NTSB), the Woods Hole Oceanographic Institution (WHOI) carried out detailed surveys of the sunken hull and debris field resulting from the October 2015 sinking of the M/V El Faro. After the survey, the NTSB commissioned WHOI to process data resulting from the surveys in support of NTSB goals. This report describes the post-processing performed on behalf of NTSB.

## Survey Background

In addition to hull-mounted multibeam sonar surveys carried out from the host vessel, the R/V Atlantis, WHOI used two subsea platforms to survey the El Faro:

- The Sentry Autonomous Underwater Vehicle. Sentry was used to perform side scan sonar surveys at a variety of coverage scales, high resolution multibeam bathymetry surveys, and low altitude still camera surveys. Figure 1 shows Sentry being deployed.

- The Alvin Observation Vehicle (OV). Sometimes called “Camper” (because the vehicle frame was adapted from a previous Camera/Sampler vehicle built in 2007); the OV was used to collect High Definition Video and still camera data. Figure 2 shows the OV on deck.

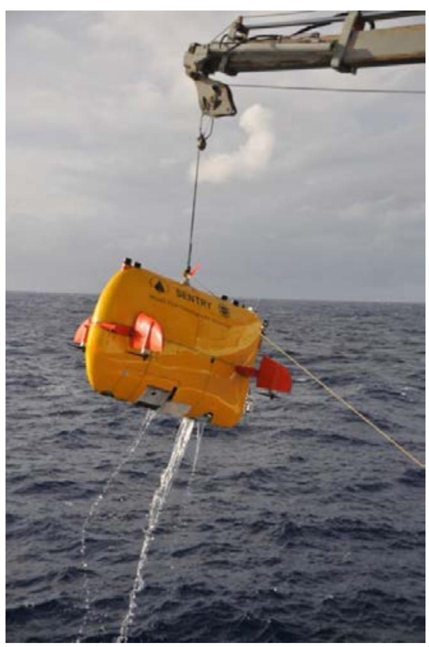


**Figure 1 The Sentry AUV**

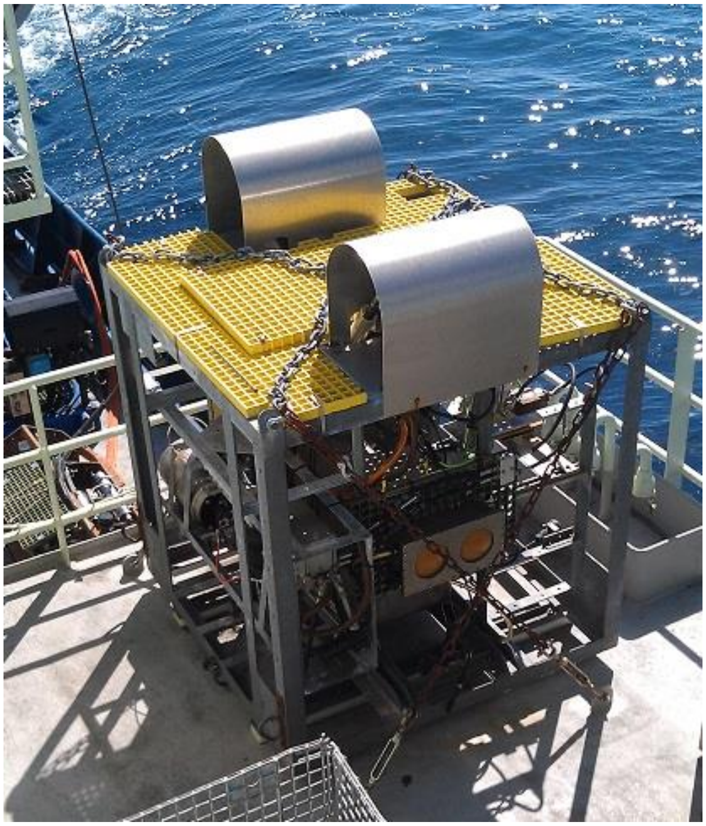


Figure 2 The Alvin Observation Vehicle (OV)

WHOI personnel performed much of the data processing necessary for use of the data at sea. For example, all of the side scan data was processed as part of the search for key pieces of wreckage, including the Voyage Data Recorder. Preliminary processing was performed on all still camera data collected by both Sentry and the OV. Results from this processing were delivered to NTSB before the vessel arrived in Woods Hole at the end of the cruise.

Post Processing Requests

The agreement and associated Statement of Work (SOW) between WHOI and NTSB concerning post-processing did not specify any specific deliverables other than a draft and final report. However the SOW anticipated post-cruise processing priorities set by NTSB in an email dialogue. These were specified as:

1. Video Data Processing. WHOI shipboard technicians generated video proxy files (low-resolution easy-to-use versions of video originals) for NTSB while on transit from the wreck site to Woods Hole. They were not able to finish before the voyage ended. NTSB requested copies of all the final video proxies. In addition, at least one of the video files delivered to NTSB proved impossible for them to view, and further processing of that file was requested.
2. Further multibeam processing. NTSB expressed interest in further processing of Sentry multibeam data covering the main hull.

3. Color Processing of OV Still Camera Images. WHOI delivered jpeg copies of the OV still camera data to NTSB before leaving Atlantis. All of the underwater imagery had a blue cast, due to the attenuation of red light by the sea water. NTSB asked WHOI if they could process the images to make them appear more natural.
4. Photomosaicking. NTSB requested photomosaicking beyond that performed on board. In particular, they requested photomosaics be prepared of the
    a. superstructure top, port and starboard sides,
    b. transom
    c. the hull crack at bay 16
    d. the lifeboat
    e. the stack
    f. the bridge

<u>Post Processing Results</u>

1. Video Data Processing.

The Atlantis SSSG Technicians continued the process of making as many proxy files as possible after the completion of the cruise. The results of their processing were archived onto a disk which was transferred to NTSB on 8 August 2016.

WHOI engineers experienced issues trying to play CAMP03_S001_S001_T0006.mov (a ProRes 422 file) as was reported by NTSB. The file was recopied from the original collection media, in case the duplication process had caused the problem. The new copy also failed to play. The symptom we saw was that although VLC would open the file and would seem to be playing it, all the video was black.

To ensure that the original collection media was not faulty, it was inserted into the Atomos Samurai deck used for collection. It played satisfactorily in the Atomos, relieving fears that the disk itself was bad.

We successfully transcoded the file to an H.264 codec in an mkv wrapper using the Ubuntu utility "h2643enc" and delivered the transcoded file to NTSB along with the proxies. Although the H.264 codec is not as useful for editing as the original collection codec, it should be satisfactory for analysis purposes.

2. Further Multibeam Processing

The Reson multibeam sonar carried by Sentry creates a depth map of the seafloor using an array of 512 individual sonar beams. Each beam measures a range from the transducer to the seafloor. Given knowledge of the beam geometry, the vehicle position, and the vehicle orientation, we can build up a "point cloud" of the seafloor or the objects on the seafloor. These points are then gridded to produce a map with equal resolution in two dimensions. The true resolution of the resulting point cloud depends on the height above bottom at which the AUV surveys as well as a combination of the vehicle speed and the sonar ping rate. Issues with the multibeam include the possibility that a particular beam may falsetrigger before the seafloor is encountered and geometric effects in irregular terrain where the seafloor or objects may be obscured in a shadow zone.

We made three types of multibeam surveys:

1. Sentry Dive 380: We covered the overall study site at our standard, most productive settings: Sentry flew at a height of 65 meters with 200 meter spaced tracklines. This survey produced a functional map, although the vehicle and sonar had several problems. The beams were misformed due to a problem with the on-board sound velocity probe. These distortions were completely removed with some non-standard post-processing. Also, Sentry had a failure with its aft control surface, so it held depth poorly and pitched significantly. This created artifacts in the map that could be reduced but not completely removed. In any case, we produced a functional map of the entire site.
2. Sentry Dives 384, 385: We surveyed a large fraction of the site with Sentry running lower (30m) to improve our resolution to better image debris. The artifacts from the first survey (sound velocity problem, poor depth regulation) were resolved before the dive. These surveys skipped the elements where we were concerned about entanglement: the vessel hull and the bridge.
3. Sentry 385: In our final dive, we surveyed the hull again at a safe height (100m) with closely spaced, orthogonal tracklines. We also reduced the coverage angle of the sonar to 100 degrees, down from its normal coverage of 128 degrees to improve coverage. By flying at a greater height with a reduced coverage angle, we preserved our coverage while improving beam geometry.

## Overall Site survey

We made an overall multibeam site survey during Sentry Dive 380. This image clearly showed the hull, the larger objects in the debris field, and numerous natural geological features.

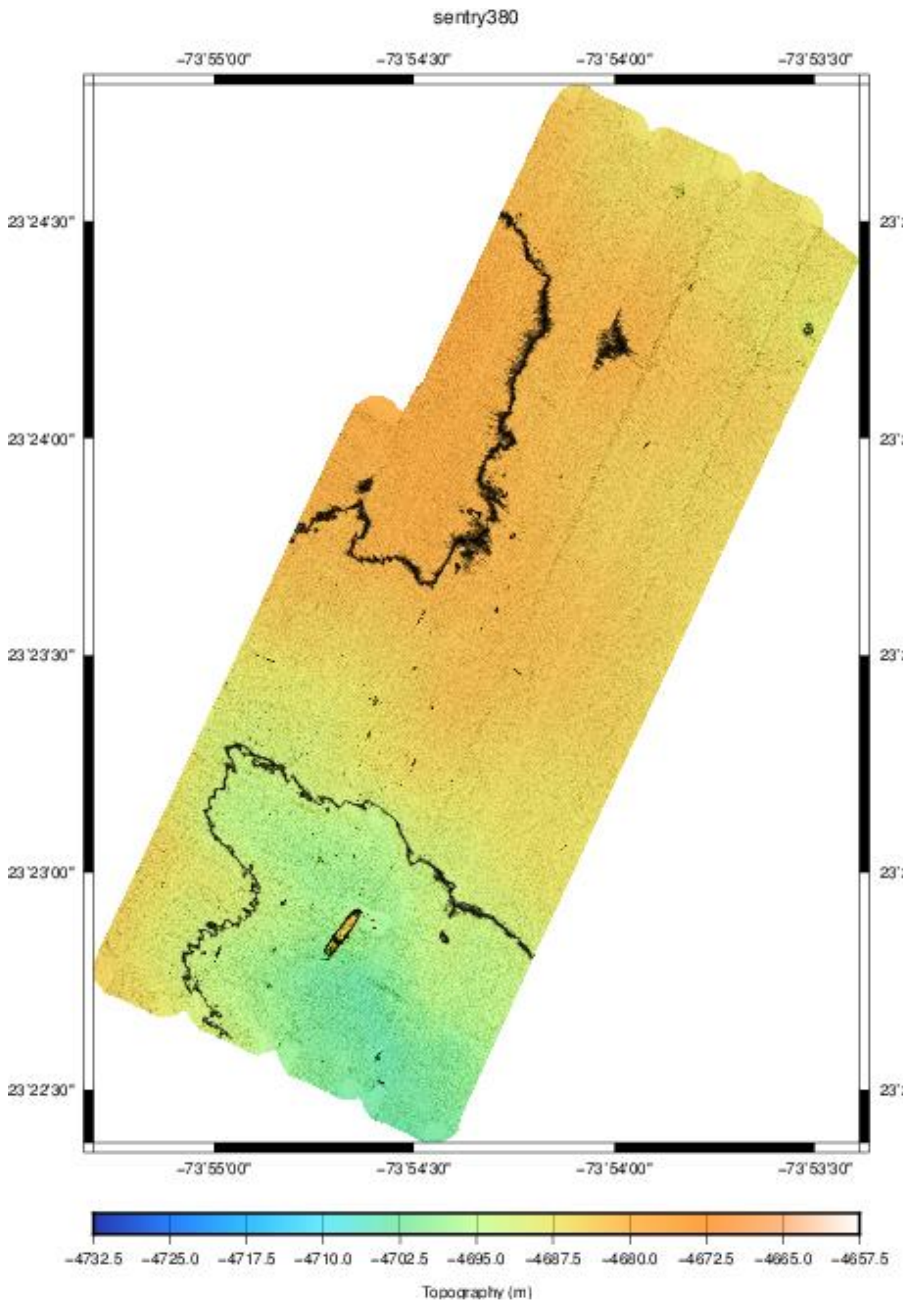



**Figure 3 Overall multibeam image of the site gridded at 1 meter**

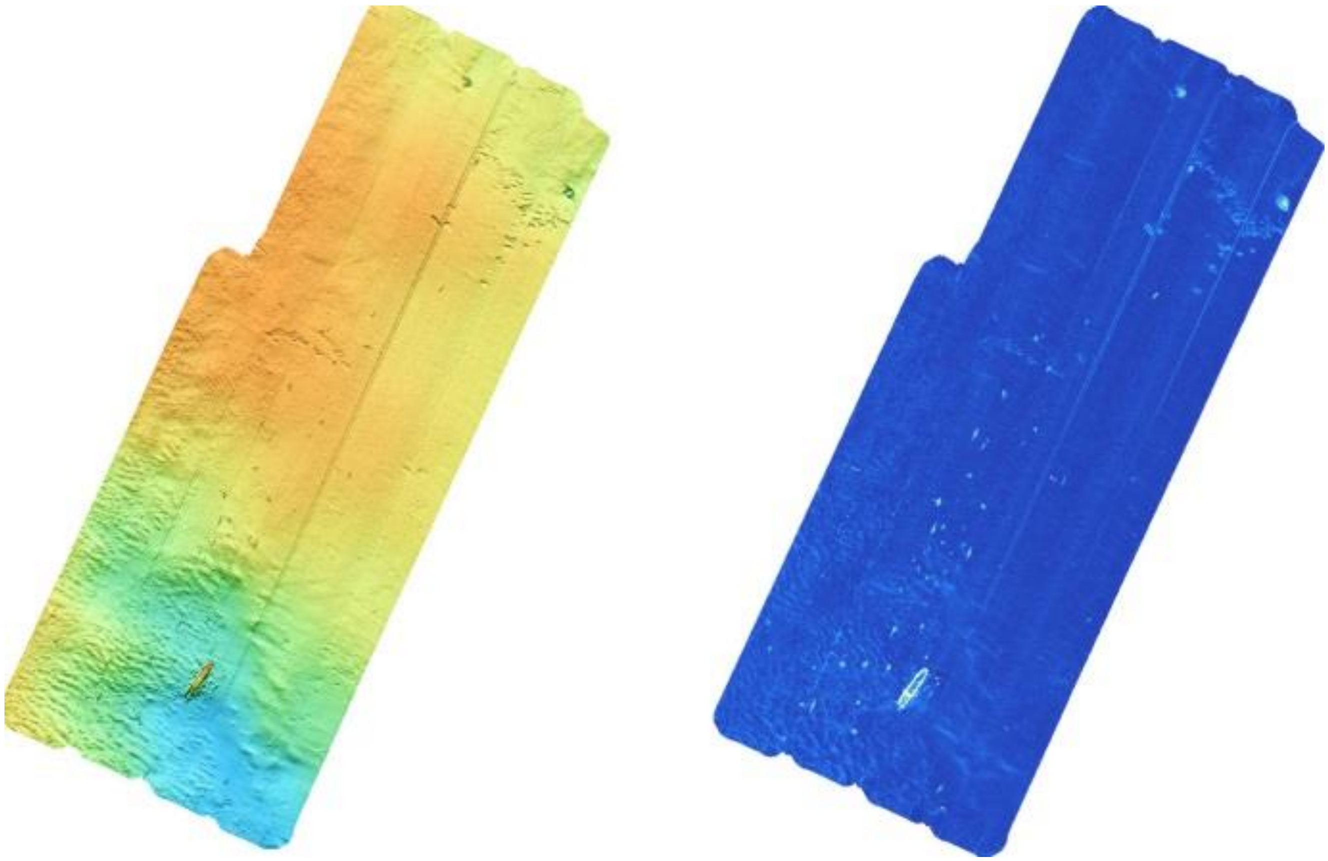


**Figure 4 These two images show some different treatments of the multibeam data. The left panel shows a different shading scheme (shading by magnitude of the slope). The right panel shows a rendering indicating the slope (spatial gradient of depth) rather than depth. These images are in the geotiff format, allowing them to be imported into other mapping and visualization packages as Arc GIS**

## High resolution survey

Over two dives, Sentry mapped the major debris areas from a height of 30 meters.

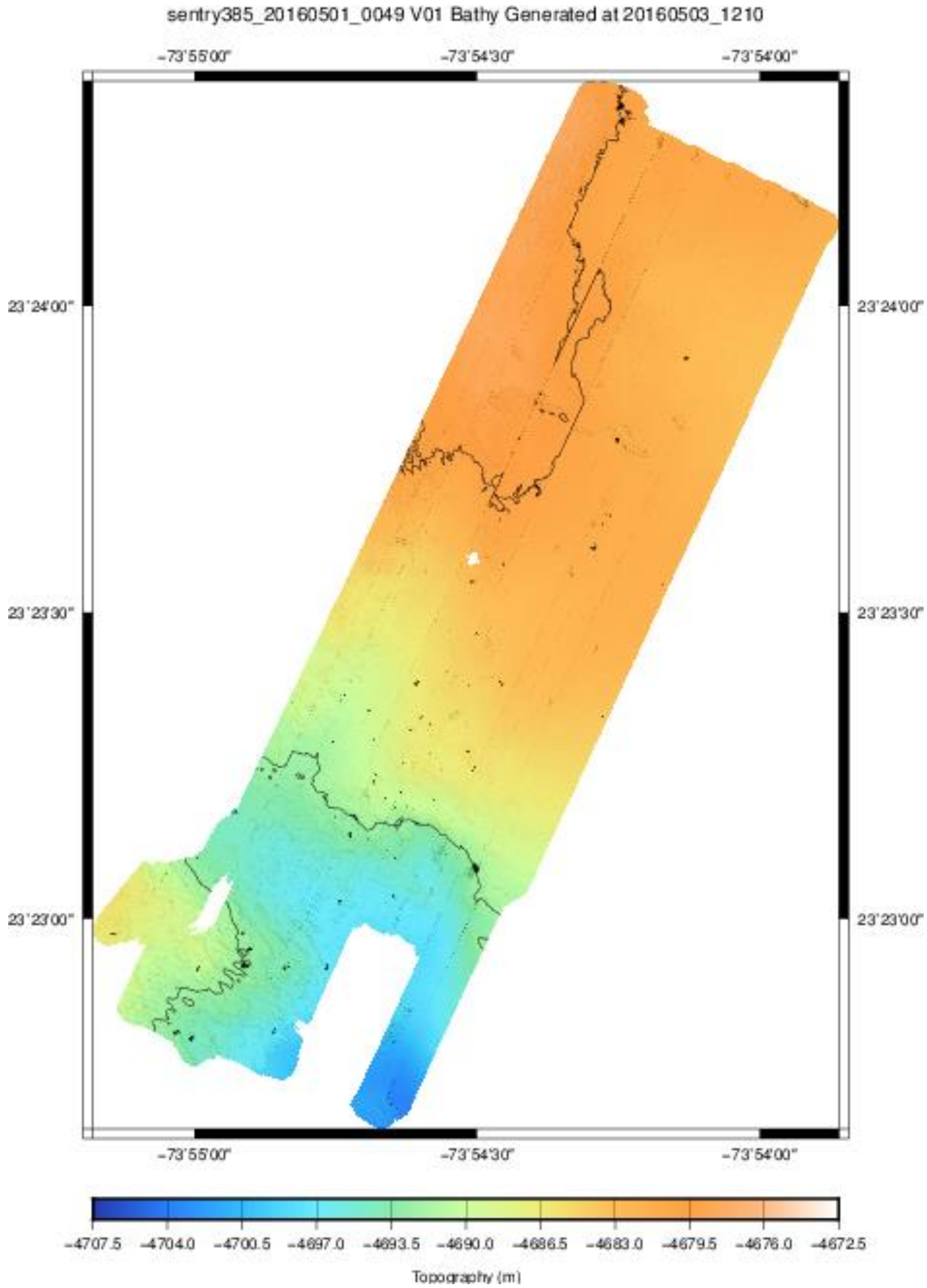



**Figure 5 This figure shows the results of the 30m height multibeam survey. We intentionally avoided the bridge and the main hull to avoid risk of entanglement**

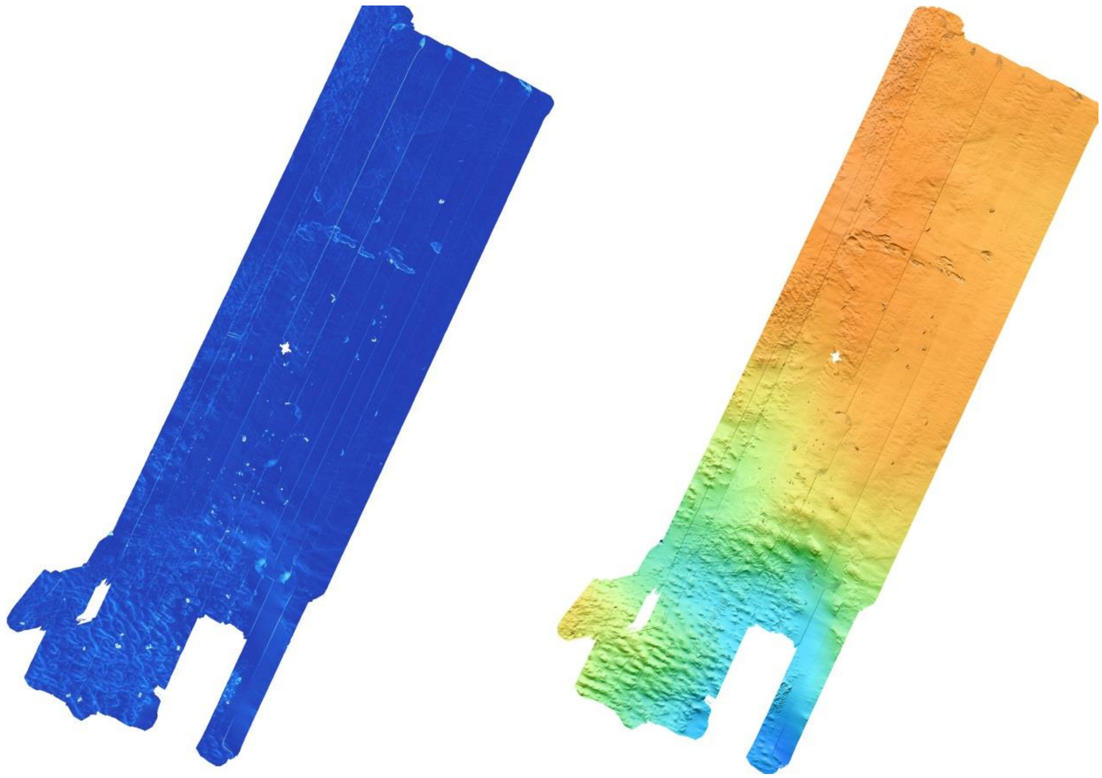


**Figure 6 As shown for the overall survey map, these panels show some different treatments of the multibeam bathymetry. The left panel show the depth with shading by slope. The right panel shows the slope (spatial gradient of depth). These renderings are useful for observing fine details and can help distinguish debris from natural features. They can directly be imported into mapping and visualization packages like Arc GIS.**

## Dense Hull Survey

On the last Sentry dive, we executed a dense survey of the hull. We made this survey at a safe height of 100m based on our best information on the maximum length of floating mooring lines as provided by the vessel owners. 100 meters is higher than our regular multibeam surveys. Additionally we ran the vehicle at constant depth to improve data quality (bottom following would re-engage if the vehicle got too close to the seafloor or any structure). If we ran with the multibeam coverage at our usual 128 degrees (width of the multibeam fan under the vehicle), many of the outer beams would have been lost. So we tightened the coverage angle to 100 degrees, and in fact we got valid returns from nearly all the outer beams. As a result, we had complete profiles with superior geometry.

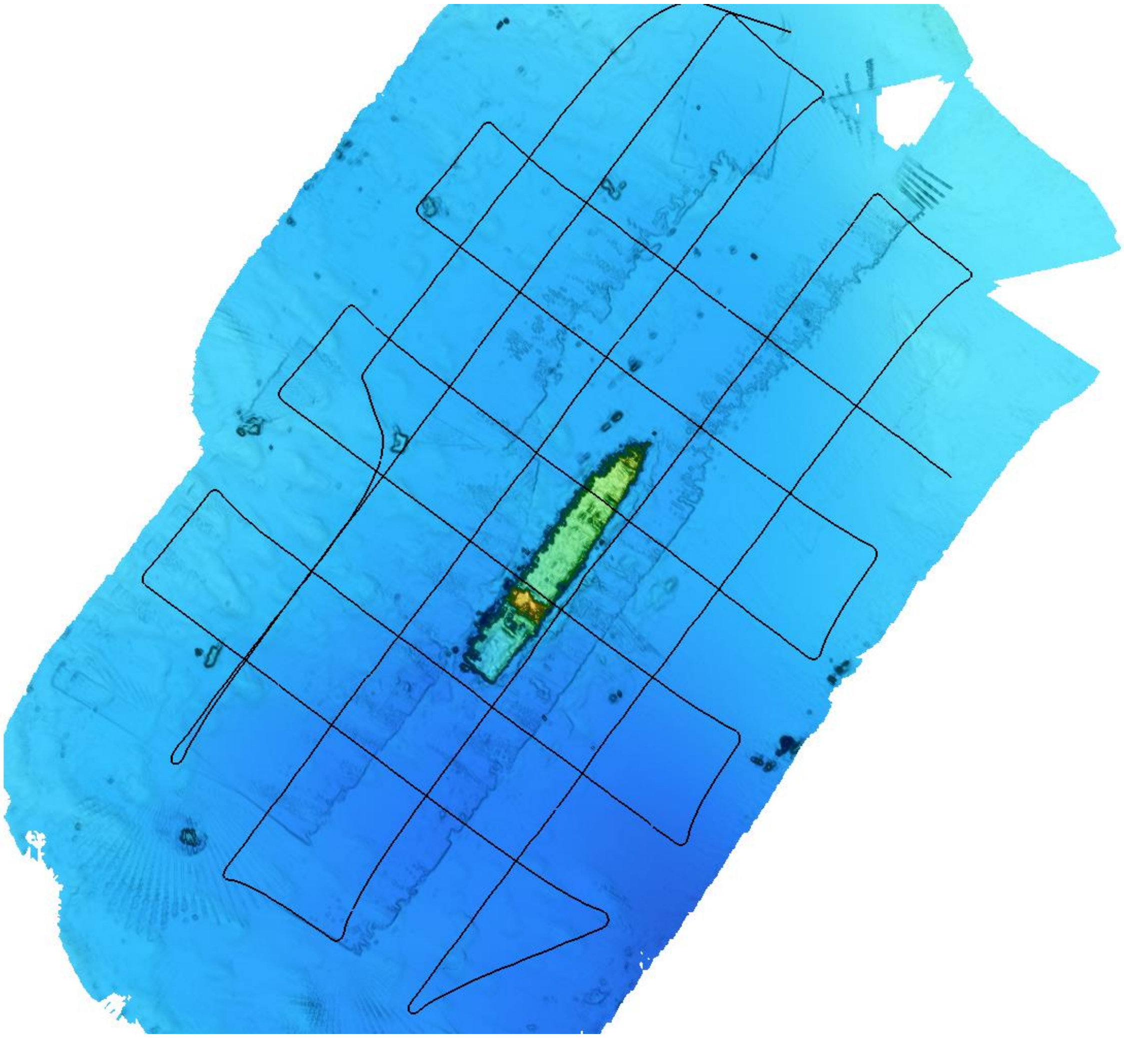


**Figure 7 This figure shows the tracklines and composite hull image for the dense hull survey. We avoided sending the vehicle over the hull for any of the along-hull tracks to reduce any chance of entanglement.**

Processing these data presents a challenge beyond those we normally face in processing bathymetry from natural terrain. Conventional gridding makes sense for simple surfaces where each point in the horizontal (xy) space has a single value of depth (z). For terrain with overlaps or overhangs, this approach will “smear” the data where more than one value is valid for a given xy combination. To solve that problem, we split the data into two sets: data at approximately the level of the seafloor and data at the deck level and above. We gridded each of these surfaces separately then combined the resulting gridded surfaces.

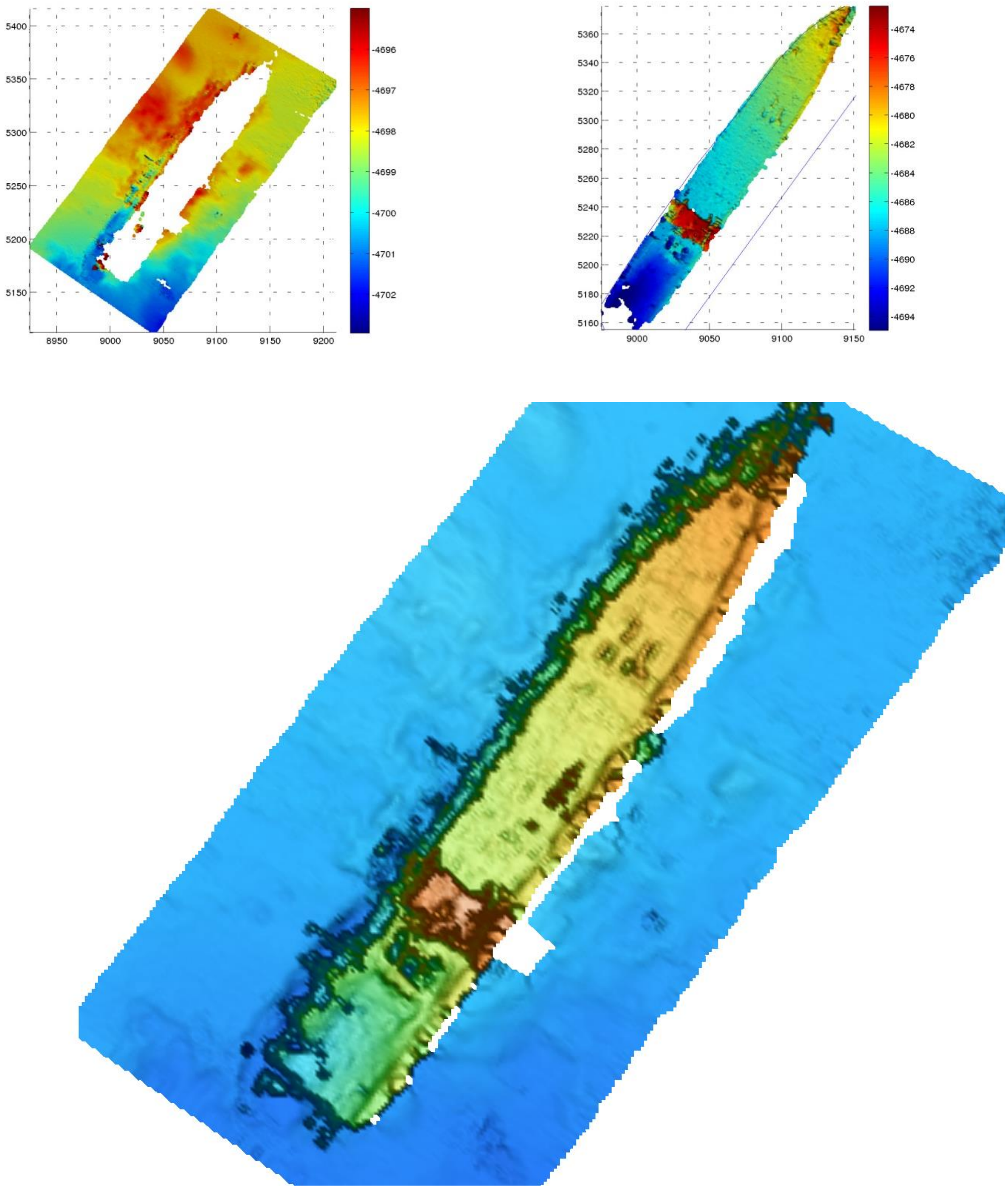



**Figure 8 These three panels show the seafloor level grid, the grid from the deck and above, and the combined view. Details in the deck can be clearly seen as well as the substantial slumping area in the stern.**

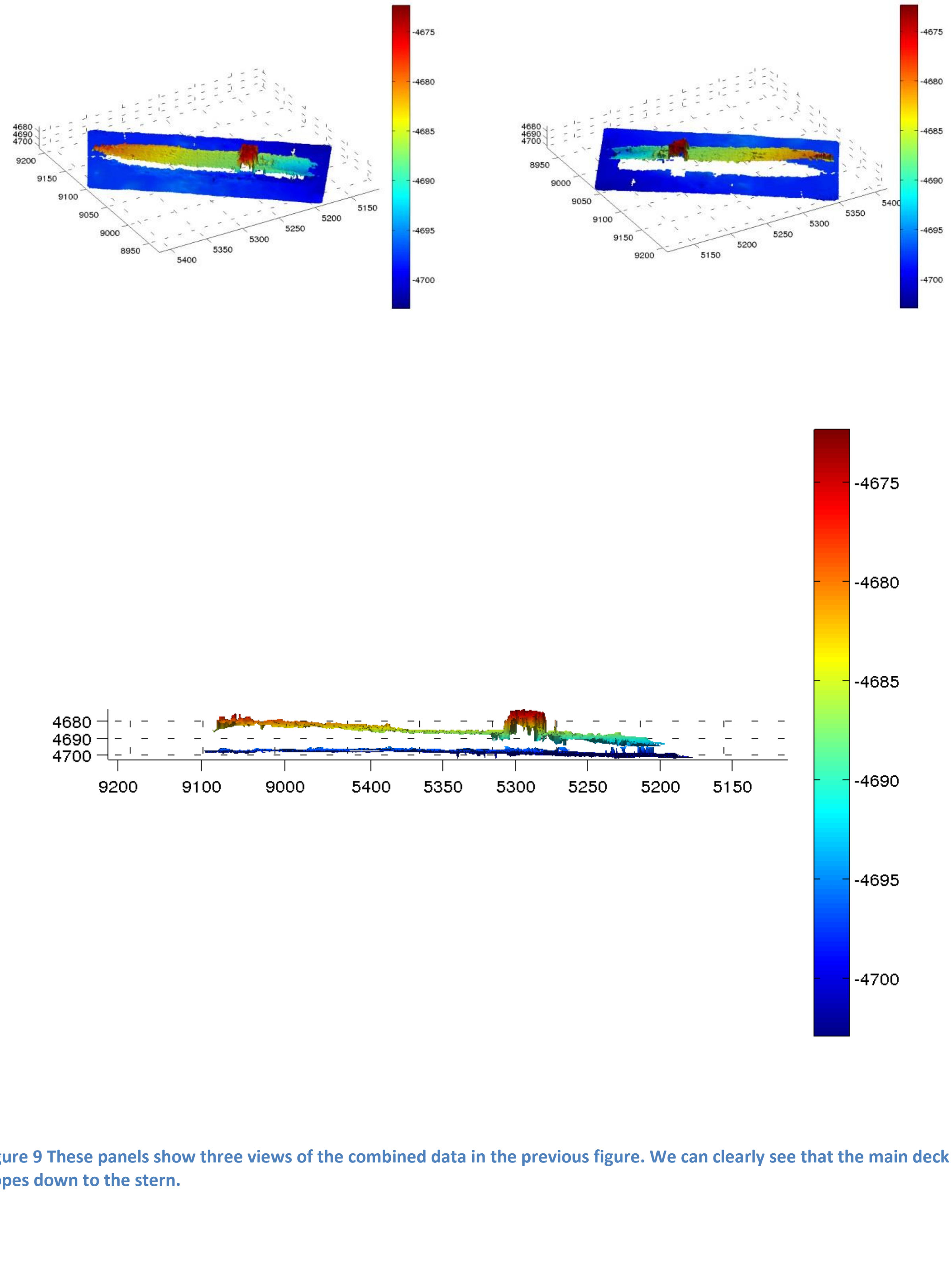
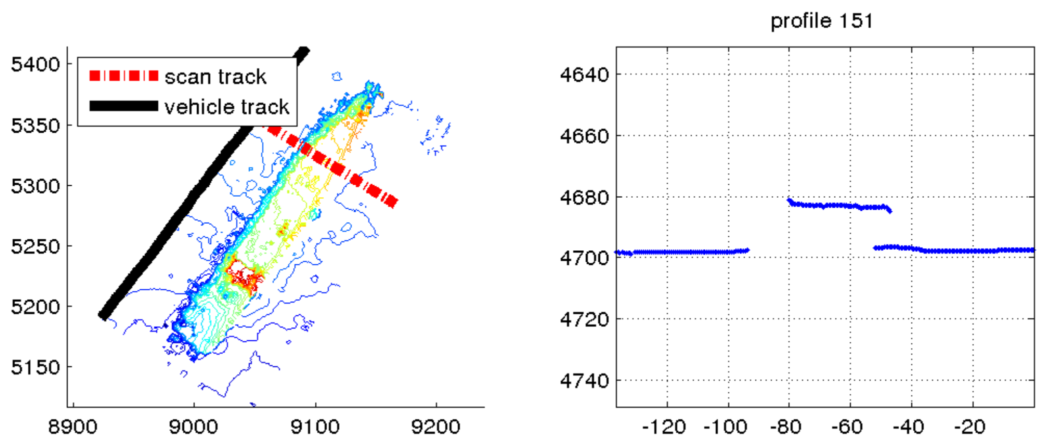



**Figure 9 These panels show three views of the combined data in the previous figure. We can clearly see that the main deck slopes down to the stern.**



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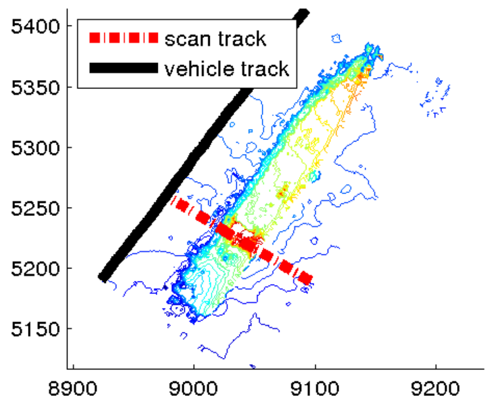

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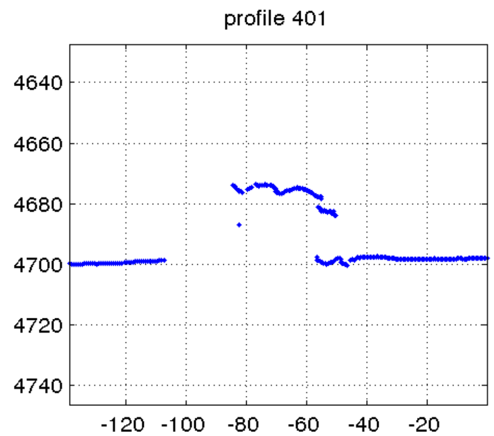

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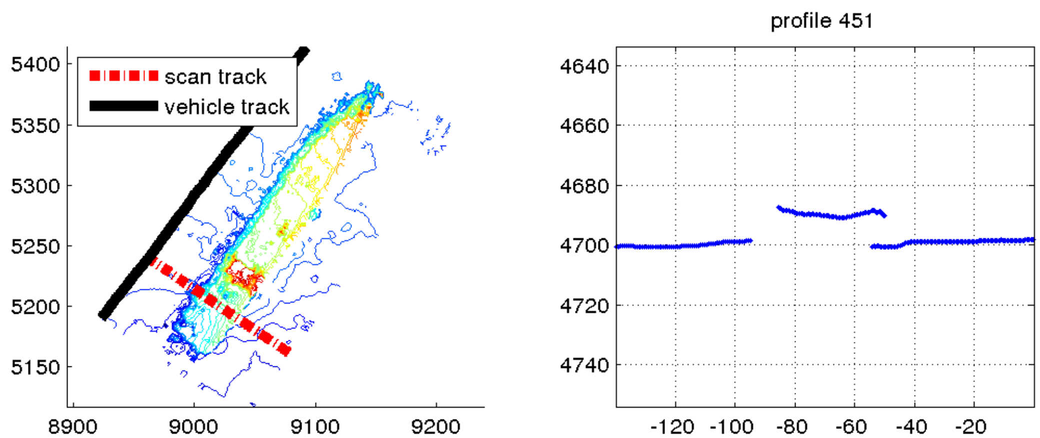


**Figure 10 We can view individual profiles to see the shape of the vessel cross-section. The first two panels show a cut through the main deck, the second set of panels shows a cross-section of the superstructure, while the third set of panels shows a cross-section near the stern.**

3. Color Processing of OV Still Camera Images.

Most underwater imagery suffers from color attenuation, and WHOI has dealt with the issue many times. A piece of software originally written for processing sea-scallop imagery was modified to process the original imagery using the “Gray World” assumption. This estimation method assumes that in a normal well balanced color image, the average of all the colors is a neutral gray. Gray World is one of many techniques for automatically white balancing images—a very similar technique using the same algorithm but a different code implementation is routinely performed on Sentry imagery. The code was run on the entire El Faro data set to produce white balanced images; the resulting data is often superior in appearance to the original “blue” imagery. The results of this processing were archived onto the same disk as the video proxies. Figure 12 and Figure 12 show a sample image before and after Gray World processing. All 112600 images were processed in this manner.

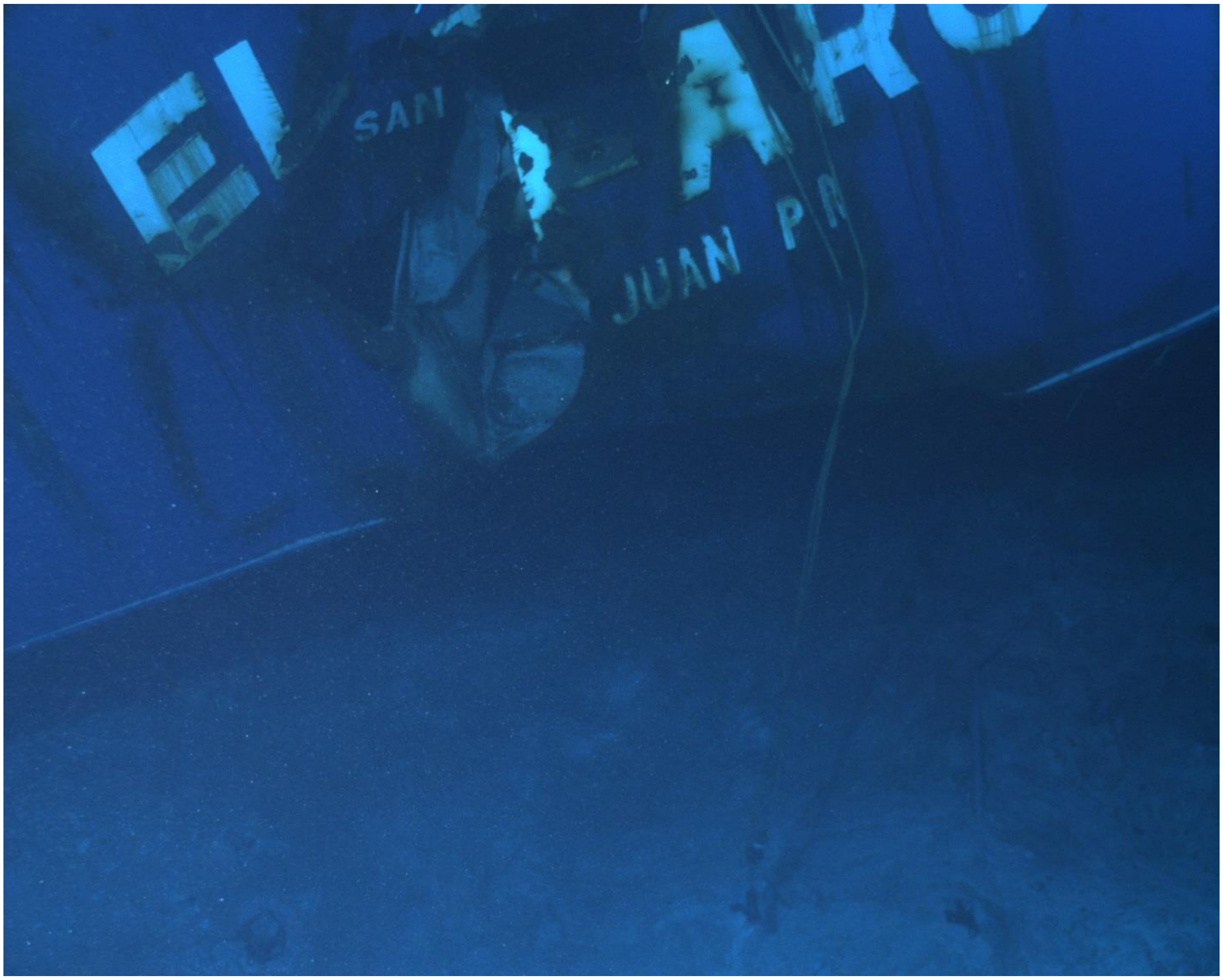


**Figure 11  Sample Still Camera Image Before Batch Color Correction**

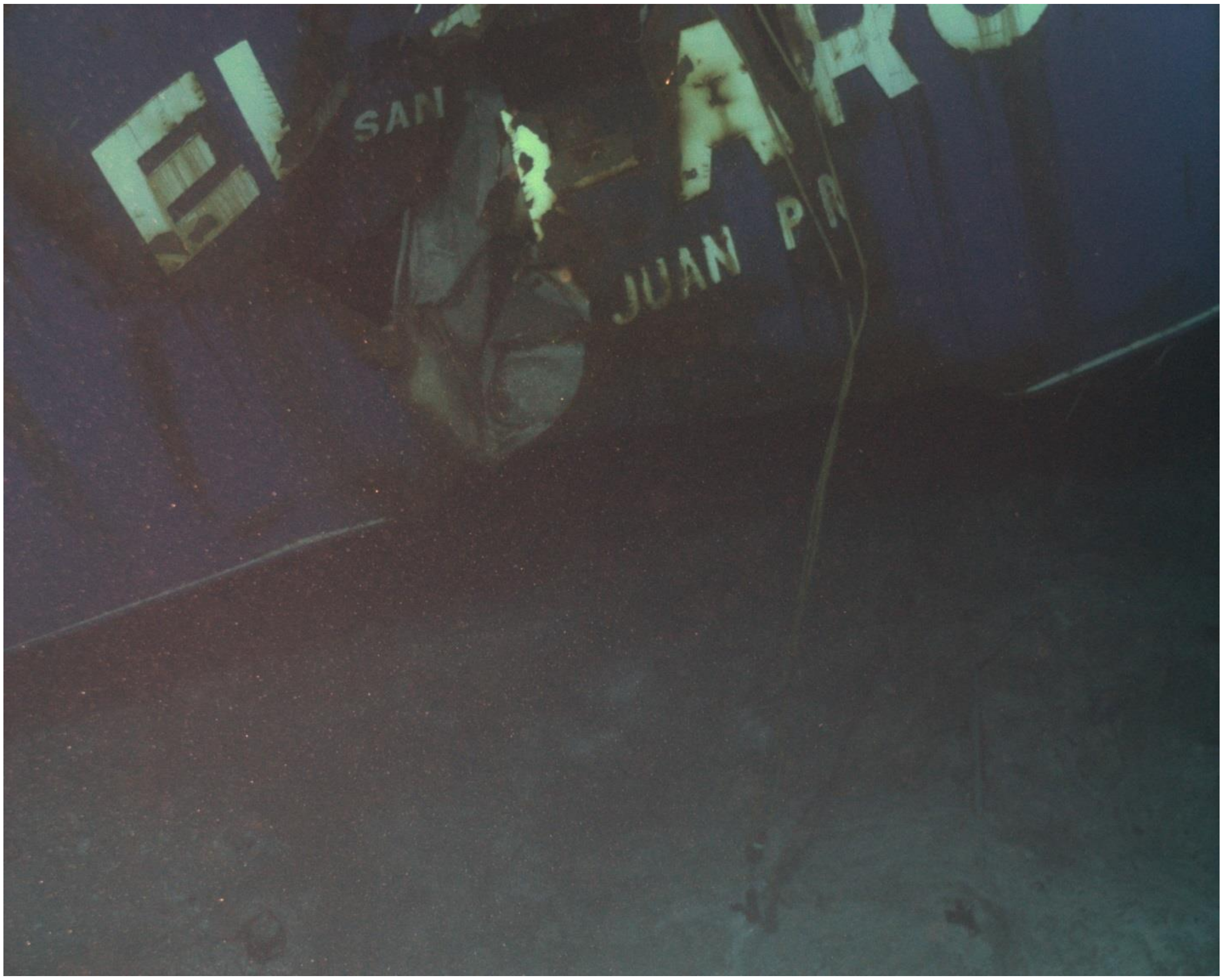


Figure 12  Sample Still Camera Image After Batch Color Correction

4. Photomosaicking

After batch processing the imagery, WHOI embarked upon producing photomosaics.

The technical challenges, geometric and otherwise, to successful mosaicking of underwater imagery are well understood and described in the literature.  Substantial progress in automated mosaicking of underwater imagery has been, and it is now relatively common for automated mosaics to be made of natural scenes underwater.  However, the close range discontinuous structures encountered in underwater imagery of shipwrecks can make automated techniques problematic so we chose to use manual tie point registration and blending to meet NTSB’s requests.

The photomosaicking performed for NTSB was accomplished using a software package called IRAS-C, a product of the Intergraph Corporation.

In the IRAS software system, images are registered (to each other and to existing mosaics) using a variety of warps, including Helmert, affine, projective, finite element, and high order polynomials. We usually use Helmert (a single scale change and rotation) and affine (scale changes in two directions) transformations. Figure 13 shows an image registration screen in use with El Faro data.

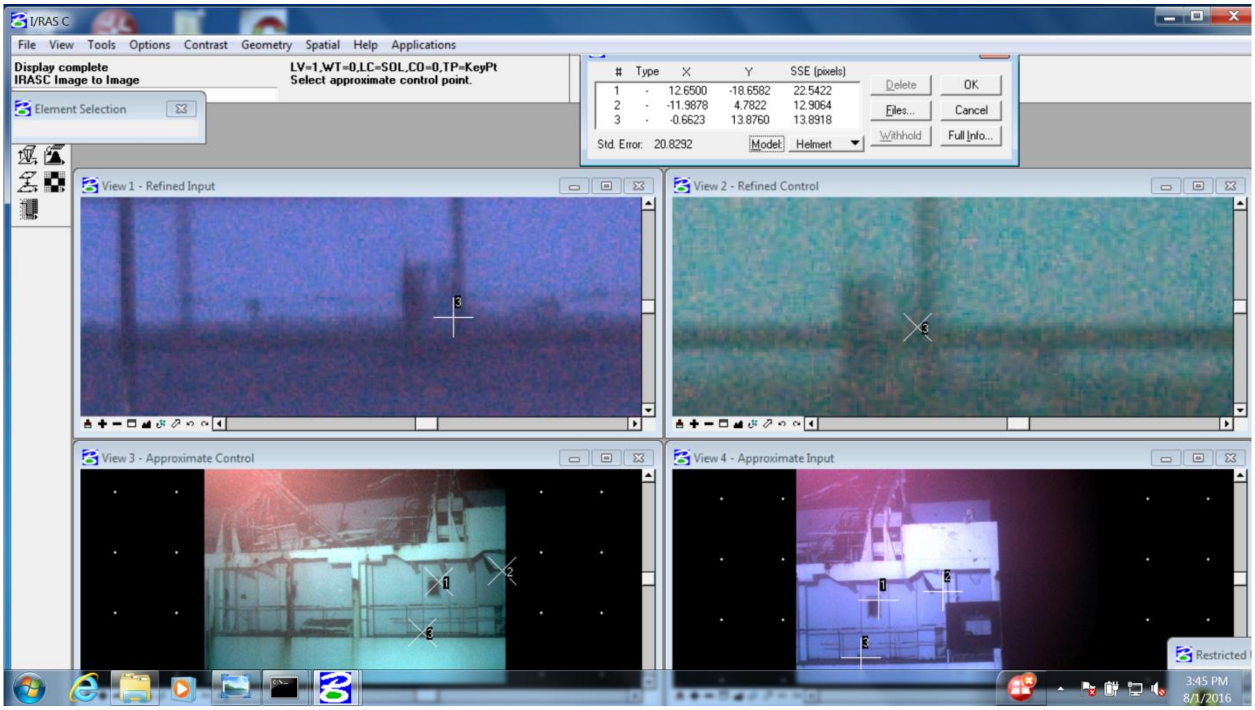


Figure 13 Image Registration Screen

Note that *no* image warp is inherently superior to any other. They are all physically unrealistic; all that can be hoped for using this methodology of mosaicking is a decent approximation and minimal distortion. In practice, several warps are tested, and the one that yields the best visual fit and the minimum RMS residual after a least squares fit is most frequently used.

After the new image is registered, it is placed into the target image or mosaic using the IRAS mosaic tool. Choices are made as to which image is placed "on top" of the other and a cut line is selected. Image cutlines are traced using manual point input. Blending can be performed across these cutlines to minimize visual edges. In practice, the most success at avoiding visible edges is found by tracking cutlines along already existing edges in the image scene, such as plate edges or railings.

After each image is added to the new mosaic, a variety of partial products are removed from the workspace and the growing mosaic is saved. Successive saving of partial mosaics allows retracing of steps. It is frequently necessary to abandon mosaics in progress, regressing to earlier steps and choosing new candidate images for input since distortions can grow quite rapidly.

It is important to stress that these mosaicking techniques do not produce a scalable map. The geometric distortions inherent in making a two dimensional projection of a three dimensional world using a multitude of small, virtually independent two dimensional projections of that world are a fundamental limitation of this approach.

Photogrammetric techniques have been used to produce more geometrically accurate and satisfying photomosaics—actually, orthophoto mosaics, since the technique requires generation of a full three dimensional model of the scene. These techniques require better navigation than was available using the OV on El Faro, and also require that the cameras—which are usually stereo cameras—are fully calibrated. None of these requirements was met for the El Faro survey.

Table 1 describes the mosaics prepared for NTSB during the processing effort. They were delivered to NTSB in a digital format (.tiff files). At NTSB's request, we created several photomosaics (imaged from different aspects) of some of the areas of interest—for example, of the bridge area. Several sample photomosaics follow the table.

| **File Name** | **Location on Vessel** |
|---|---|
| break_hull.tif | Crack in the hull |
| bridge6.tif | bridge |
| bridgepart2b.tif | bridge |
| broken_davits3.tif | Life boat davits |
| crack2a_stern.tif | Crack in the hull at stern |
| crack_16.tif | Crack in the hull |
| crack_16_17.tif | Crack in the hull |
| ElFaro.tif | stern |
| ElFaro2.tif | stern |
| Foot2.tif | Transom area |
| house_destruct1.tif | superstructure |
| housetop5.tif | superstructure |
| intact_davit1.tif | Life boat davits |
| intact_davit2.tif | Life boat davits |
| intact_davit3.tif | Life boat davits |
| intact_davit3a.tif | Life boat davits |
| intact_davit4.tif | Life boat davits |
| ladders4.tif | superstructure |
| lifeboat_bow1.tif | Lifeboat on sea floor |
| livingq4.tif | superstructure |
| scr8.tif | superstructure |
| stackhole5b.tif | superstructure |
| sternpanorama5a.tif | stern |
| bow5mos.tif | Bow (created on board) |
| bridgemo4.tif | Bridge (created on board) |
| funnelmo1.tif | Funnel (created on board) |
| mastmo1.tif | Mast (created on board) |
| mastsidemo3.tif | Mast (created on board) |
| mos4.tif | Mast detail (created on board) |

Table 1: Mosaics delivered to NTSB.

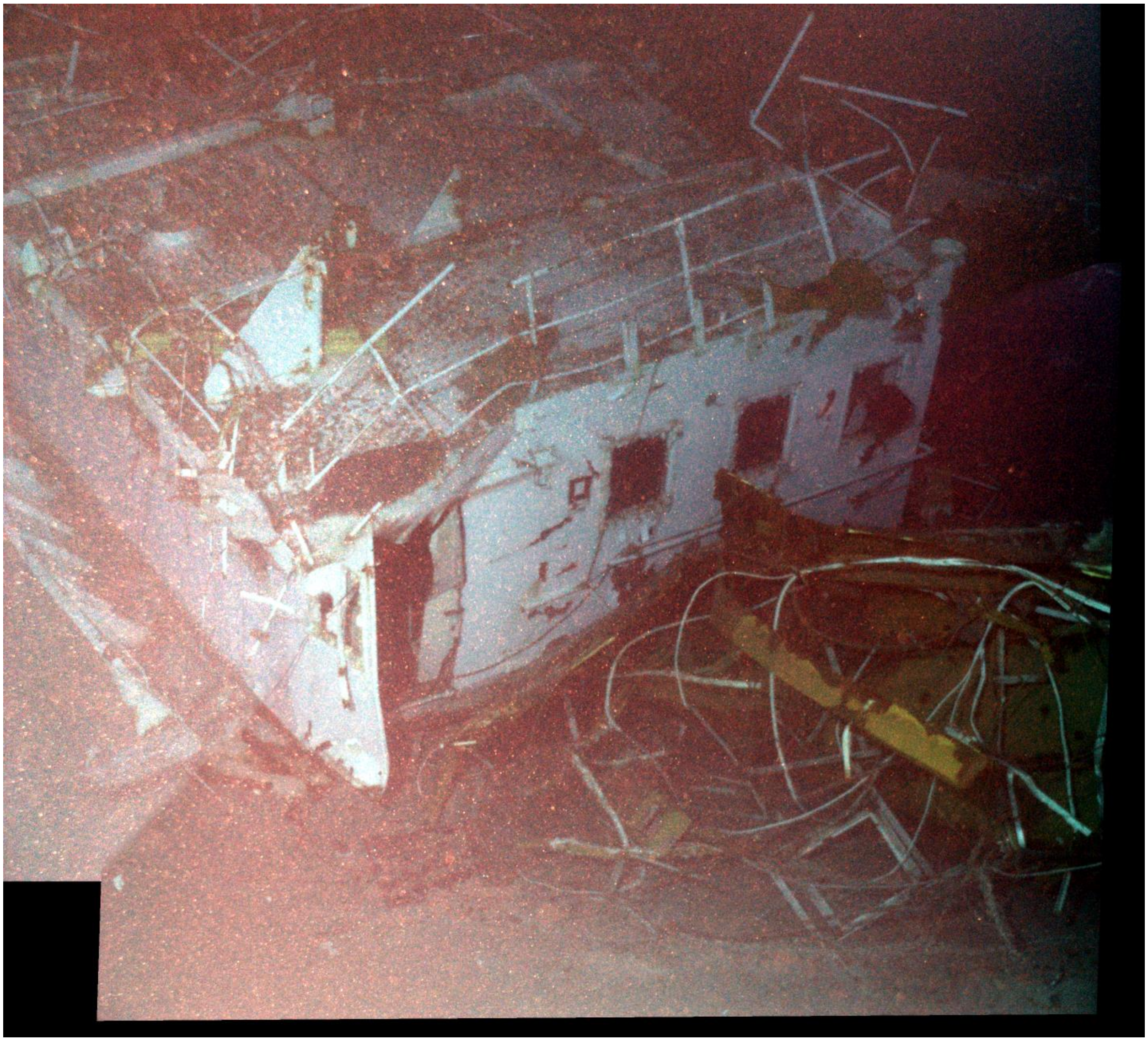

**Figure 14 Mosaic of Bridge Structure**

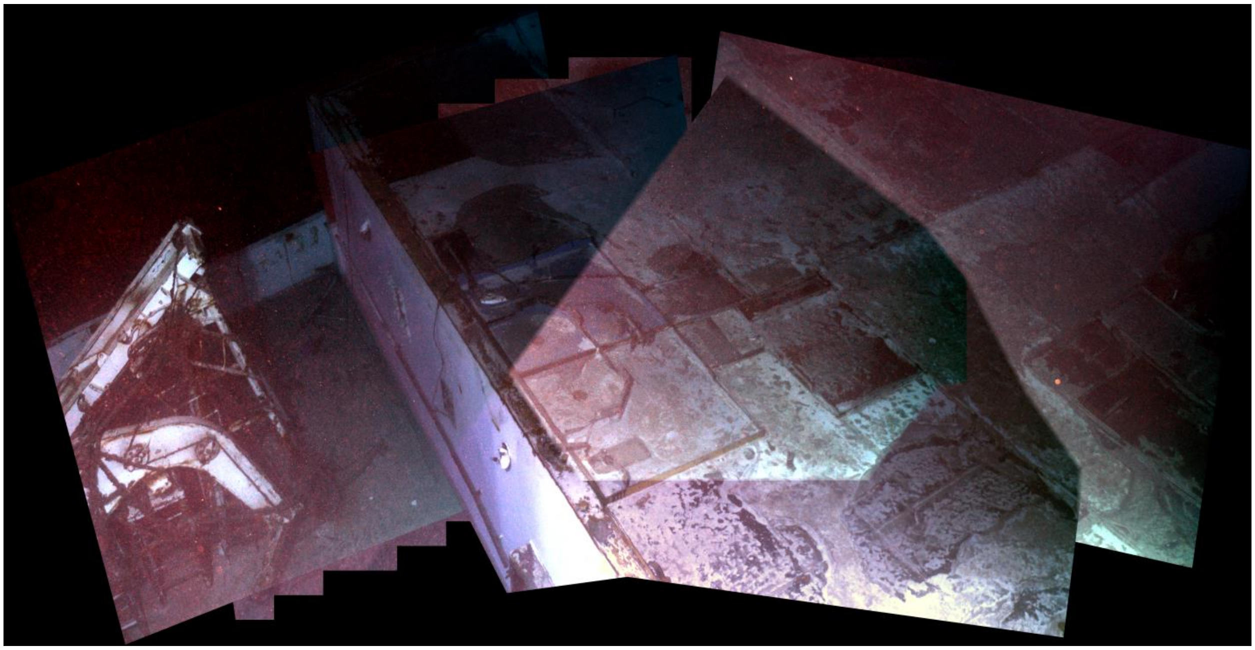

Figure 15  Mosaic of Top of Bridge Structure

Figure 16  Mosaic of Ladder Section of House

## Delivery of Post Processing Results

WHOI delivered interim products (transcoded video files, color balanced imagery) to NTSB during the course of the processing effort. Along with the submittal of this report, we are sending data to NTSB comprising digital copies (tiff format) of all of the photomosaics prepared and of the multibeam processing products. With the raw data being delivered onboard, this should constitute complete delivery of all products specified in our Statement of Work.

More detailed and exacting versions of some of the multibeam results are still in preparation and will be sent to NTSB as a Supplement to this report and to the original data delivery. This Supplement should be sent to NTSB within a few days of the delivery of the rest of the data.

The WHOI personnel who led and/or performed the processing efforts are available for questions and clarification should it be necessary. Their contact information is below:

Sentry On-Board Processing: Carl Kaiser, [redacted]

Sentry Multibeam Processing: Dana Yoerger, [redacted]

OV Imaging, Image Processing, and Mosaicking: Jonathan Howland, [redacted]

Overall Expedition Leader: Andrew Bowen, [redacted]